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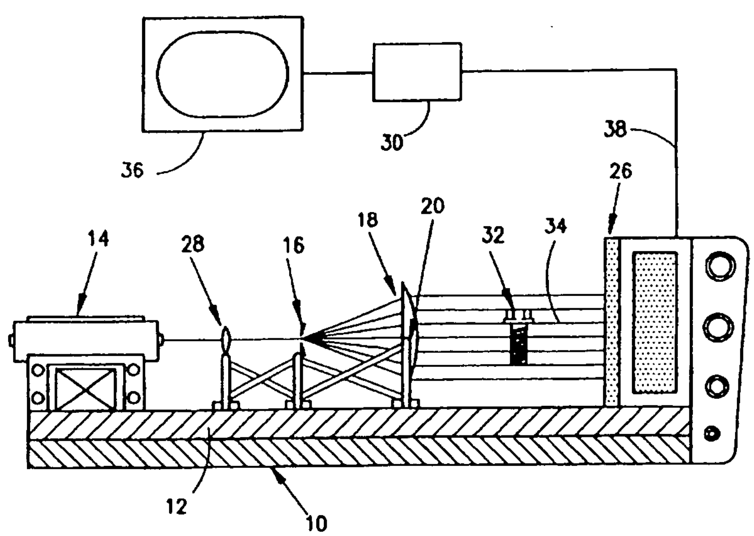

(57) Abstract

A non-contact gaging method and apparatus develops the sharply defined silhouette spanning opposite edges of an object (32), measuring the silhouette of bolts (32) and other threaded fasteners, to determine thread pitch, pitch diameter, major and minor diameter, flank angle, length of thread engagement and other fastener dimensions, to high accuracy. A laser (14) provides a beam which is focused by an object lens (28) on a pinhole in a shade (16), providing a point source from which the beam diverges. A collimating lens (18) produces a collimated broad iluminating beam (34) of laser light dimensioned to encompass the object (32). The illuminating beam is incident on a planar two-dimensional detector array (26). An image processor (30) counts pixels between light/dark transitions to provide precise dimensional measurements that are compared to stored values to reach an accept/reject decision as objets (32) pass the gaging system.

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HIGH SPEED OPTO-ELECTRONIC GAGE AND METHOD FOR GAGING

Background of the Invention

1. Field of the Invention

The invention relates the field of opto-electronic methods and apparatus for quickly and automatically gaging the dimensions of precision objects. In particular, the invention concerns video image collection and analysis for rapid gaging of the dimensions of workpieces such as fasteners comprising threaded screws or bolts, using collimated laser imaging techniques to obtain a precise two dimensional pixel image subject to data analysis, whereby precise measurements are taken from a pixel image silhouette of the respective workpiece.

2. Prior Art

Mechanical fasteners, threaded and unthreaded, are widely used in our technological society. In many applications, certain dimensions of the fasteners are critical to how well and smoothly the fasteners engage mating fasteners. There is a need for precise gaging to assess the quality of such fasteners with respect to dimensions. However, for practical considerations it would be advantageous if the accuracy, completeness and speed of gaging could be maximized, while at the same time minimizing the complexity and expense of the gaging method and apparatus.

There are a number of criteria by which the quality of fasteners can be assessed. Several characteristics of threaded fasteners such as screws, bolts, threaded shafts and the like, are very apt to provide a useful measure of their quality. These include, for example,

shank diameter, perpendicularity, eccentricity and certain specific thread measurements such as minor and major diameter, thread pitch, pitch diameter, flank angle, length of thread engagement and the like. By comparing the actual dimensions of fasteners to maximum and minimum tolerances in each of these respects, one can obtain a good measure of how well the fasteners will fit a mating fastener, a machined opening or the like. Parts can be accepted and rejected on this basis as a part of quality assurance steps. On the other hand, any measurements advantageously are accomplished at least as quickly as the parts are produced, so that quality assurance does not become a bottleneck. Generally, it has been necessary to make tradeoffs between quality assurance measurement and production speed, for example by taking fewer than all the measurements that would be advantageous from a quality assurance standpoint, or by sampling the parts and only taking complete measurements on a subset of the parts to assess the quality of all the parts.

Prior art devices and methods take at least one minute or more to accurately gage a fastener's dimensions. Because of this, it is not possible to timely gage each fastener in a batch of fasteners to determine if each falls within a specific tolerance. It is not uncommon that only a small percentage of the fasteners in a batch be gaged. Sometimes this percentage is as low as one one-hundredth. If this select group passes, the entire batch [illegible] accepted as passing.

Various methods have been disclosed for measuring fasteners as to those particular dimensions that are considered the most important. Such measurements can be more or less automatic. The vast majority of such methods involve the use of mechanical devices such as feeler gages comprising wires, balls and pins or

micrometers, which physically bear against the fastener to be dimensioned. The primary disadvantages of such methods are that they are time consuming, often required manual action by an operator, are subject to operator error due to fatigue, difficult to standardize or keep calibrated, and generally are not conductive to automated quality assurance inspection as a production step.

The invention is directed to a particular opto-electronic method and apparatus for taking high speed non-contact measurements in an automated manner. Optical detection of objects has been attempted in the prior art for making dimensional measurements, and generally involves either illuminating an object or backlighting it, and then detecting transitions of luminance characteristic of edges. For outer edges of an opaque object, accurate object edge detection is possible by employing back illumination of the object to produce a transition in light intensity in a collected image, between the dark object, more accurately its backlighted silhouette, and the bright background. Where the object is placed immediately in front of a diffuse backlight source, a focused image of the object can be collected.

A laser beam can be arranged in a collimating optical system for taking a measurement. For example, in U.S. Patent No. 3,941,484 - Dreyfus, an object is backlighted by use of a laser and a collimating lens or mirror that expands the point source laser light to encompass an object to be examined. The object partly occludes the expanded beam and provides an image. Additional lenses concentrate the beam at a point or scanning tube arrangement, such that the luminance of the collected light is serialized like a raster image. The serial luminance level is sampled repetitively in conjunction with a threshold comparator and timing means

to locate the edge of the object from a change in the amplitude of the luminance signal. The comparator data, in connection with timing data, can be converted into a dimensional measurement.

A scanning arrangement is inherently serial, and as a result, the scanner can sense light intensity from the beam at only one position at a given time. Timing considerations affect the accuracy of the measurement. Moreover, scanning arrangements are prone to further error if one attempts to apply them to moving part.

U.S. Patents 4,576,482 and 5,114,230, both to Pryor, disclose methods in which collimated laser light is used as a back-light to collect luminance information by finding the transition in luminance across a single edge of an object. The light is partly occluded by the object and is applied to a linear photodiode array having an extension perpendicular to the edge. The object can be a cam or the like that is rotated in conjunction with the measurement to define the contour of the cam surface. The Pryor technique is also serial in that it detects the luminance transition along a line. The collimated beam is not wide enough to profile both edges of the object simultaneously. Furthermore, an array is not used to detect the resulting silhouette.

U.S. Patent 4,315,688 - Pryor discloses utilizing reflected light rather than an occluded backlight source, to check the quality or at lest presence of fastener threads. Reflected light typically produces low accuracy measurements when used to gage fastener dimensions. An image of a portion of the threads of a fastener is created on a single sensor and the output signal is analyzed to determine thread quality.

It is known to collect and analyze a two dimensional image of an object by opto-electronic methods employing digital video imaging means, including performing dimensional measurements. An image of an

object or its profile is focused on a two dimensional detector array, for example of a video camera. The image is digitized, often together with image enhancement techniques intended to produce better edge contrast. A computer or other electronic processing device processes the digital information to locate edges and other relevant image points by finding transitions in luminance. Various object dimensions are then determined from the pixel position displacements between transitions in luminance. With a proper setup, measurements can be made quickly and accurately, even of objects moving rapidly on an assembly-line conveyor. The accuracy of the measurements performed with such methods is limited by several factors, including the fidelity of the input image. A number of factors influence image quality, the specifics of illumination, imaging optics, the detector, and the placement of the object to be measured play dominant roles.

Thread quality gaging is a particularly demanding imaging problem that has not been solved completely by digital imaging methods, especially where use of a lens is involved. The invention eliminates a need for a focusing lens. Previously it was necessary to accurately position the focusing lens in space a certain distance from the object being measured in order to produce a shadow identical in size to the object. In the invention, use of collimated light is instrumental in providing a shadow which is the same size of the object, without a need for a lens and the attendant problems of correctly positioning the lens with respect to the object and otherwise focusing the image.

U.S. Patent No. 4,644,394 - Reeves discloses examining external threads on a pipe, using a collimated laser beam to back-light the threads along one side of the pipe. A luminance transition thus is detectable at a tangent of the pipe surface. An image of the pipe

threads at one angular point on one side of the pipe is collected and processed and enables certain thread measurements in that area. However, in order to make related thread measurements at other angular points around the pipe, for example to determine pipe diameter or to relate thread data in different areas, it is necessary to rotate the pipe or to move the camera around the pipe axis (keeping the collimated source aligned to the camera). A metered rotation drive means can be used to rotate the pipe (or orbit the camera and source), so as to enable the data applicable to different points along the threads to be related together. For example, one then can associate the data at 180 degree opposite points for measuring diameter. However, it is necessary to rely on the accuracy of the rotation drive means and the ability to accurately position the part at different angular positions around the rotation axis. These drive requirements introduce time constraints and measurement inaccuracies.

Three patents assigned to the Boeing Company (U.S. Patents 5,150,623, 4,828,159 and 4,823,396) disclose digital imaging methods which utilize back-lighting to gage fastener dimensions. U.S. Patent 4,823,396 - Thompson discloses a method in which a fastener is back-lit by an array of LED's (light emitting diodes). A video image is created of the fastener profile, which is then digitized and processed to verify thread presence, discriminate between fasteners with helical and parallel threads, measure thread length and perform various dimensional measurements on the head and shank of the fastener. The accuracy of the measurements performed is dependent on the distance between the camera lens and the fastener. Without collimated back-lighting, slight variations in the distance translate to variations in the apparent size of features in the image on the camera detector array, and consequently measurement errors.

Such uncertainties are significant when fasteners must be dimensioned to within tight tolerances, for example for use in the aerospace industry.

Patents 4,828,159 and 5,150,623 both issued to Woods, disclose methods which attempt to remedy the above problem by using two cameras, imaging the fastener from two orthogonal directions and mathematically calculating the position of the fastener at the time of imaging. The calculation of precise fastener position is dependent upon precise focussing of the cameras. An image that is even slightly out of focus will lead to an error in the calculated position, and consequent error in measured fastener dimensions.

SUMMARY OF THE INVENTION

An object of the invention is to provide a non-contact means for gaging the quality of a plurality of fasteners.

A further object is to provide a video image method and device for which variations in fastener positioning with respect to the detector array have minimal impact upon fastener dimension measurements.

Another object is to minimize labor-related errors by providing an apparatus and method which is simple to use and involves a minimum of component parts.

Yet another object is to provide a method and apparatus which does not suffer from the measurement uncertainties created by an out of focus image or image degraded by lens aberrations introduced through the use of an image lens.

Another object is to provide a method for measuring fastener dimensions that can be standardized and that will lend itself to the inspection of fasteners at the high rate of speed necessitated by high speed production methods.

A further object is to improve the accuracy and

speed of fastener measurements by collecting simultaneously pixel data representing a full silhouette of a part illuminated by a collimated back-lighting laser incident on a detector array, whereby dimensions can be determined directly from the pixel displacement of luminance transitions, i.e., to collect highly accurate data on both edges of a fastener at once.

These and other objects are satisfied according to the invention, while also solving the problem of fastener placement. The invention preferably employs a non-contact method and apparatus for gaging the important dimensions of a plurality of fasteners for production reporting, quality assurance, selection/rejection decisions and the like. Dimensions are determined rapidly and to high accuracy by using customized software developed inhouse. A fastener whose dimensions are to be determined preferably is positioned by mechanical means immediately opposite a two dimensional solid state detector array, of the kind used in CCD or CID cameras. The fastener can be positioned, for example, by means of a vacuum check or conveyor bracket, so that the fastener is disposed with its long axis in a known orientation, e.g., substantially-vertical. It also is possible to manually position the fastener. The fastener is back-illuminated by a highly collimated laser beam which impinges on the detector array at normal incidence, providing parallel light rays oriented perpendicular to the longitudinal axis of the fastener. The laser beam is opened by collimating means to encompass at least two opposite edges of the fastener simultaneously. The fastener occludes or eclipses part of the beam, thereby producing a silhouette of the fastener. Due to the collimation of the beam the silhouette can be cast on the detector array without the use of an interceding imaging lens for focusing.

The detected luminance of the image is digitized to

define pixel values encoded at least to discriminate light and dark pixels by comparison with a threshold luminance, and also potentially to permit image enhancement using gray scaling to precisely define edges. Image processing means are utilized to locate the silhouette edges and relevant points thereon to high (pixel or better) accuracy and fastener dimensions are then determined by appropriate proprietary algorithms. The decision to accept or reject a particular fastener is based upon comparison of such dimensions with customer or industry standards.

It is an aspect of the invention that by use of collimated laser back-lighting, for creation of a silhouette without the use of an imaging lens, and employment of a high precision CID detector array to parallel-load the silhouette image spanning at least two opposite sides of workpieces, a fast and efficient means and method for automatic workpiece inspection is provided. Inspection of each workpiece may be accomplished in as little as one second.

Use of a highly collimated beam for back-lighting according to the invention provides several advantages over prior art methods. The technique provides greater latitude in fastener placement. It minimizes the effects of minor changes in the distances between the fastener and the light source and detector array, thereby reducing the time for evaluation of the fastener. It also permits variation in the orientation of the fastener with respect to the detector array, which array is sized to encompass the silhouette such that accurate dimensions are quickly and readily obtainable from the pixel image data. It is possible to collimate the beam of laser light so that the angular divergence of parallel rays is as small as 1 arc-second. When an object is back-lit with such a beam, a 1cm variation of the displacement of the object from a

position 10cm from the detector array translates geometrically to only a 5 millionths of a centimeter change in the size of the silhouette produced on the array. This is about one-tenth the wavelength of the light and is inconsequential in comparison with errors introduced by diffraction effects and from other sources.

Image data on the part silhouette is collected in a strobe or snapshot fashion. This provides for the possibility of rotating a single fastener in place and taking images of various edge profiles, for example at regularly spaced angular positions around the longitudinal axis of the fastener. However, each of the profiles can provide full lateral measurements. Slight displacements of the light/dark transitions in the successive silhouettes, including displacements due to rotation, have minimal effect on the fastener silhouette or the measurements available by processing the image data. Finally, use of a highly collimated laser beam for back-lighting in conjunction with a two dimensional CID or CCD detector array ensures a precise, essentially one-to-one, correspondence between a fastener and its silhouette. Highly collimated laser beam illumination also minimizes grazing edge reflections which can make precise edge location difficult and hence degrade measurement accuracy.

Additional advantages are provided according to the preferred means for creating a silhouette of the fastener, wherein no imaging lens is provided between the fastener and the detector array for focusing the image. Measurement errors resulting from image degradation due to lens aberrations are eliminated. Since no focusing is required, fasteners of different diameters can be inspected with little or no adjustment to the setup. Since a full width silhouette of the fastener is incident on the detector array, with or

without the use of a condenser, diameter measurement errors that are inherent in metered rotation and/or successive illumination of opposite object edges with independent beams or with the same beam at different times, are avoided. By thus eliminating the need for precision fastener placement and the use of an orthogonal camera setup, the inspection procedure and mechanical requirements are considerably simplified. The invention thus makes possible a more compact and cheaper setup.

Since there is no imaging lens in front of the camera, diffraction effects are minimized by placing the fastener as close as possible to the camera array. For this reason the thickness of the transparent plate, placed in front of the two dimensional detector array, is kept to a minimum. The transparent plate is scratch resistant, resistant to breakage under mechanical impact and coated with an anti-reflective coating at the same wavelength as the interrogating laser beam. The procedure requires that once the collimated beam is incident on the two dimensional array the object, whose dimensions are to be determined, occludes the collimated beam. The diffraction effects are minimized by placing the object immediate to the transparent plate and hence to the two dimensional detector array.

The detector array can comprise light sensitive charge-coupled devices (CCD) or charge-injection devices (CID). Preferably, however, a CID array is used. Such a detector array has the advantage that its individual pixel detector elements are arranged contiguously, with no space between adjacent pixels. This makes possible the precise location of the object edges to within 15 microns in the pixel image. In addition, since each CID pixel is individually addressed, the x,y coordinates of each edge point can be accurately determined using direct data processing steps. Finally, CIDs provide

improved accuracy because they are immune to the "blooming" or streaking problems to which CCDs are subject when high intensity light source such as lasers are employed for fast imaging purposes. Although CCD arrays have recently beam introduced which have contiguously arranged pixels and are resistant to "blooming", such CCD arrays are expensive as compared to CIDs.

CID and CCD detector arrays are known to increase in cost as array area is increased. Often the cost of a single detector array exceeds the cost of two detector arrays which are half its size. It is preferable, therefore, to use a detector array having a relatively small area. Occasionally, a fastener will have a dimension exceeding one or both of the height and width of the detector array. In such cases it is possible to employ two small detector arrays in a side-by-side arrangement to gage the over-sized fastener. In cases where the fastener has, for example, a width greater than the combined width of side-by-side arranged arrays, the arrays may be separated from each other as necessary to ensure that the far edge of each array is set-out from a respective edge of the fastener. The pixels of the arrays are appropriately re-addressed through the software. The system can be calibrated by placing a high precision ruler in the path of the collimated beam to cast a shadow on both detector arrays simultaneously. The data obtained is compared to the actual dimensions and adjustments made as necessary to the array positioning or addressing.

These and other objects and advantages of the invention will become apparent in connection with the following description of certain preferred embodiments of the invention and the accompanying diagrams.

Brief Description of the Drawings

There are shown in the drawings examples of embodiments of the invention as presently preferred. It should be understood that the invention is not limited to the precise arrangements and instrumentalities shown in the drawings, wherein:

FIGURE 1 is a top plan view of the device of the invention.

FIGURE 2 is a partly schematic side elevation view thereof.

FIGURE 3 is an end elevation view in the direction of illumination, i.e., from the left in FIGURES 1 and 2.

FIGURE 4 is a front plan view of a silhouette image on a detector array as produced by the device of the invention.

FIGURE 5 is an elevation view of a fastener as imaged according to FIGURE 4.

FIGURE 6 is a front plan view of a silhouette image of a rivet on a detector array as produced by the device of the invention.

It should be noted that the object or workpiece to be gauged is located in a collimated beam. Thus, since there is nothing between the object and the sensor array, a silhouette is cast on the array that is the same size as the object. There is a one-to-one dimensional relationship. This is called a collimated silhouette.

For purposes of clarity, the object to be gauged is shown diagrammatically spaced from the sensor array. Actually, the objects can be located closely adjacent the optical array. In any event, because the beam is collimated, variations in the distance between the object and the optical sensor array will not materially effect the one-to-one relationship. It will be a collimated silhouette.

Detailed Description of the Preferred Embodiments

FIGURES 1 through 3 show a preferred embodiment of a fastener inspection device according to the invention. The system includes a steel plate 12, which can be disposed on a base vibration isolation system 10 for preventing vibrations from the conveyor or other workpiece transporting device from being communicated to the measurement system. A laser light source 14 is mounted on plate 12 at one end such that the beam axis is aligned with the longitudinal center-line of the plate 12. Also mounted on plate 12 and positioned along its center-line are certain optical components intended to remove random fluctuations from the intensity profile, to expand and to collimate the laser beam. The laser beam has a predetermined beam width as emitted from laser source 14 which is larger than the video camera array size. In order of increasing distance from the laser, an objective lens 28 focuses the laser beam at a point through the aperture of a pinhole in shade 16. A lens mount 20 and a plano-convex lens 18 are preferably used to collimate the laser beam. Collimating plano-convex lens 18 is normal to the optical axis, and is precisely spaced along the optical axis from pinhole shade 16 by a distance equal to the focal length of lens 18. Accordingly, the rays from the laser are aligned by lens 18 to be parallel to one another and to the optical axis, over a height and width that is larger than the height and width of the workpiece or part of the workpieces 32 to be imaged and measured.

A planar solid state video sensor array 26 is disposed behind the workpiece 32 and due to the parallel alignment of the beam rays receives a sharp silhouette of the workpiece regardless of precisely where the workpiece is located along the optical axis. No lens is provided in front of sensor array or camera 26. The

aperture of the pinhole 16, collimating lens 18, and camera 26 are oriented such that the axis and center of each lie along a line defined by the light propagation axis of the laser beam. The camera or detector array 26 likewise is oriented normal to this axis.

A fastener positioning system 22 positions the workpiece 32, in this case a threaded bolt, in the path of the collimated beam 34, between lens 18 and CID camera 26. An image processor 30 and preferably a display monitor 36 are coupled to camera 26, for example by cable 38, such that the luminance information for each pixel in detector array 26 is provided to the image processor.

The image processor 30 can include means for addressing the pixel elements in the detector array 26, an analog to digital converter (not shown), and associated timing means. The image processor can be triggered to commence an image measurement cycle whenever a workpiece 32 arrives in the field of view, and to collect a series of images as workpiece 32 passes, preferably while being rotated by positioning system 22. The images are collected in a strobe or snapshot freeze-frame fashion.

The laser 14 outputs a narrow beam of light which impinges upon the objective lens 28 and is focussed through the pinhole aperture of shade 16 essentially at normal incidence. The objective lens 28 and pinhole 16 act to provide a point light source for the plano-convex lens 18. The beam emerging from pinhole 16 diverges radially from the pinhole located at the focal point of plano-convex lens 18. A portion of the light is intercepted by plano-convex lens 18, which refracts the light rays by an amount that is a function of their angles of incidence on the air/glass boundaries at the surfaces of lens 18. The laser beam is thereby collimated.

The distance between the pinhole 16 and the plano-concave lens 18, and the area of lens 18, are functions of the area of detector array 26, and preferably are chosen such that the collimated beam has a width substantially corresponding to the receiving area of array or camera 26. The rays of the collimated beam which emerges from the lens 18 are parallel to the optical axis of the lens and normal to the plane of the detector array 26. Between the plano-convex lens 18 and the camera 26, a collimated beam 34 with divergence of 1 arc second or better can be produced.

The fastener 32 preferably is suspended from the positioning system 22, for example via a vacuum chuck, with its axis within a few degrees of vertical. The fastener 32 is a positioned so that it lies entirely within the collimated beam, and therefore casts its full shadow or silhouette on the detector array 26. Fastener 32 occludes part of the highly collimated laser beam 34, thus producing a dimensionally precise silhouette of the fastener on the detector array 26. FIGURE 4 is a diagram showing the silhouette image 44, superimposed on a pixel matrix 42 of the camera or detector array 26. As shown in FIGURE 4, the silhouette has dimensions corresponding to the size of the real object, namely a fastener 32 such as bolt 50, shown in FIGURE 5. The dimensionally precise silhouette 44 of the fastener 32 is subdivided by the illuminated or occluded individual pixels 42 of the detector array. Though not to scale, FIGURE 4 shows small dot size which represents the center of the pixels.

Figure 6 is a diagram showing the silhouette image 54 of a rivet superimposed on a pixel matrix 42 of the camera or detector array 26. As shown in Figure 6, the silhouette has dimensions corresponding to the size of the real object. The dimensionally precise silhouette 54 of the rivet is subdivided by the illuminated or

occluded individual pixels 42 of the detector array. Though not to scale, Figure 6 shows small dot size which represents the center of the pixels.

The edge of the silhouette is determined by sampling the pixels in the dark region where the shadow is cast to obtain an average of gray scale values. The unshadowed pixels are subsequently or possibly concurrently sampled to obtain an average of their gray scale values. The average gray scale value of the shaded region is subtracted from the average gray scale value of the unshaded region and the result multiplied by 0.25 (25%). The processor searches for all pixels having the calculated number of these represent the edge of the fastener. It is important to avoid saturating the pixels with laser illumination. With this technique, an edge can be determined to better than 1000th of an inch, and even greater to 100,000th of an inch if subpixel interpolation is employed and by employing a two dimensional array with smaller individual pixel dimensions.

The pixels are each classified as light or dark based on the luminance level detected at the respective pixel. This can be accomplished by analog or digital threshold comparison techniques. Image processing routines or by using the theory of diffraction for edge detection and incorporating it into the subroutines, as known in the art, can be applied to the pixel data to enhance the contrast of the edge and/or to better define the nominal edge, to eliminate isolated contrasting pixels and otherwise to enhance the image data.

The processor 30 also measures the silhouette image for critical dimensional features. For example, the major and the minor diameter of the fastener is calculated by counting the number of occluded pixels along horizontal lines through the image, at any or all of the thread positions. The count of occluded pixels

is multiplied by the known pitch or distance between the centers of the pixels, which of course are regularly spaced. All such calculations are accomplished in the programming of the processor, preferably measuring not only major and minor diameter, but also thread pitch, pitch diameter, flank angle, longitudinal length of thread engagement and other criteria. The measurements can be compared to stored selection criteria such as nominal measurements and tolerances for acceptable parts. A deflection apparatus (not shown) can be arranged downstream of the measurement system, and coupled to the processor to divert selected or rejected parts, or to sort parts based on the selection criteria and measurements.

The processor controls array or camera 26 for collecting one or more images of the fastener when in the field of view. The camera 26 preferably is electronically shuttered so that it records the silhouette when the fastener is located in the beam and occluding the detector array. An additional photodetector (not shown) can be provided to produce a triggering signal when the fastener is at a predetermine position and breaks a beam. According to a preferred embodiment, a CIDTEC™ camera operating in synchronous capture mode is employed. This CID camera makes possible precise image capture of moving objects without the use of a strobe light.

Image processor 30 can rapidly locate silhouette edges in the pixel image data, and the pixel pitch or center spacing allows measurements to be taken to an accuracy of better than one thousandth of an inch, thereby allowing accurate selection based on criteria such as thread profile and other fastener dimensions. Many of the pixel capture and data analysis functions can be performed with frame grabber/image processing boards, available for example from Data Translation™.

Operations on the data output by those boards, such as measurement and analysis of the dimensions as compared to nominal dimensions, and control and timing functions, are performed with a standard computer workstation or laptop computer with sufficient processing speed, such as a computer having an Intel 486 processor or the like.

The fastener inspection system as shown and described can dependably determine pertinent dimensions of fasteners such as bolts, screws and the like, compare the measurements to selection criteria, and operate selection/rejection actuators, all at production speeds. These dimensions used to select or reject can include pitch diameter, flank diameter, major diameter, minor diameter, thread height, thread pitch, shank diameter, length of thread engagement, fastener perpendicularity and the like. It will be appreciated that other dimensions may also be pertinent with respect to fasteners or parts of a different character.

The invention has been described with respect to certain preferred embodiments but is subject to variation within the scope of the appended claims. Reference should be made to the following claims rather than the foregoing specification as indicating the true scope of the invention in which exclusive rights are claimed.

I Claim:

1. A video imaging device for determining the dimensions of an object, comprising:

a laser light source providing a propagating beam of laser light along a beam path;

means for diverging the beam, providing an angularly divergent beam from a point along the beam path;

means for collimating said angularly divergent beam, intercepting the angularly divergent beam and providing a two dimensionally expanded collimated beam of substantially parallel rays;

positioning means operable to position a workpiece to be imaged in the collimated beam, the collimated beam being sufficiently large to encompass at least two opposite sides of the workpiece, the workpiece partially occluding the collimated beam to provide a silhouette including edges corresponding to the two opposite sides;

an optical sensor array for detecting a pixel image of the silhouette, the sensor array comprising a plurality of discrete light sensitive elements, the collimated beam and the silhouette being incident on the sensor array;

a processor coupled to the sensor array operable to determine dimensions of the workpiece from the pixel image.

2. The device of Claim 1, wherein the means for diverging the beam produces a point light source at said point along the beam path, the beam diverging from the point light source.

3. The device of Claim 2, further comprising an object lens operable to concentrate the laser beam at

the point light source.

4. The device of Claim 1, wherein the means for diverging comprises a shade having an aperture, the laser beam being incident on the aperture in the shade.

5. The device of Claim 3, wherein the object lens concentrates the light on an aperture in a shade for diverging the beam from a point source defined by the aperture.

6. The device of Claim 1, wherein the means for collimating the beam comprises a plano-convex lens having a focal length, the plano-convex lens being disposed at a distance from the point along the beam path equal to the focal length.

7. The device of Claim 1, wherein the means for detecting the collimated beam comprises a charge injection device (CID) detector array.

8. The device of Claim 1, wherein the means for detecting the collimated beam comprises a charge coupled device (CCD) detector array.

9. The device of Claim 1, wherein the means for computing dimensions comprises a microcomputer.

10. The device of Claim 1, wherein the positioning means comprises a conveyor operable to sequentially convey successive workpieces into a position within said collimated beam and immediately adjacent the detector array.

11. The device of Claim 10, wherein said workpieces are threaded fasteners.

12. A video imaging device for determining dimensions of an object, comprising:

a laser operable to produce a laser beam along an axis;

a shade disposed along the axis, having a pinhole aperture to pass and diverge the laser beam;

an objective lens disposed between said laser and said shade, for focusing said laser beam on the pinhole aperture, whereby the pinhole aperture forms a point light source;

a collimating lens along the axis, having a focal length and being spaced from the shade by a distance equal to the focal length, the lens collimating the laser beam and producing a collimated illuminating beam of parallel rays, the illuminating beam having a height and a width;

a detector array comprising a plurality of discrete light sensitive sensors, the illuminating beam being incident on the detector array for illuminating pixel positions defined by the sensors, the detector array being planar and normal to the illuminating beam;

means for disposing an object to be measured within the illuminating beam, whereby the object casts a silhouette on said detector array;

an image processor coupled to said detector array, including a processor operable to compute dimensions of the object based on positions of edges of the silhouette defined by transitions in luminance between adjacent pixels positions as detected by the detector array.

13. The device of Claim 12, wherein the detector array comprises a charge injection device camera and wherein the detector array is exposed directly to the collimated illuminating beam, whereby the silhouette is casted on the detector array without an intervening focusing lens.

14. The device of Claim 12, wherein the detector array comprises a CCD camera and wherein the detector array is exposed directly to the collimated illuminating beam, whereby the silhouette is casted on the detector array without an intervening focusing lens.

15. The device of Claim 12, wherein said detector array is comprised of rows and columns of pixels having a predetermined regular pitch spacing, and wherein the image processor is operable to count pixels between the transitions and to multiply a pixel count by the pitch spacing for obtaining a dimensional measurement of the object.

16. The device of Claim 12, wherein the means for disposing the object in the illuminating beam comprises a conveyor operable to carry successive objects into the illuminating beam and immediately adjacent the detector array.

17. The device of Claim 12, wherein said objects are threaded fasteners.

18. The device of Claim 17, wherein the image processor is operable to measure at least one of pitch diameter, flank angle, major diameter, minor diameter, thread height, thread pitch, shank diameter, length of thread engagement and fastener perpendicularity of the objects.

19. A method for determining the dimensions of an object, comprising:

using a laser light source having a propagating beam of laser light to product a laser light beam along a beam path;

angularly diverging said beam from a point along

said beam path;

collimating said angularly divergent beam to provide a two dimensionally expanded collimated beam of substantially parallel rays of said beam;

positioning a workpiece to be imaged within the collimated beam, said workpiece partially occluding the collimated beam thereby providing a silhouette of the workpiece;

detecting a pixel image of said silhouette on an optical sensor array; and

computing dimensions of the workpiece from said pixel image.

20. The method of Claim 19, further comprising concentrating the beam prior to angularly diverging the beam.

21. The method of Claim 20, wherein an objective lens is used to concentrate the beam.

22. The method of Claim 19, wherein a shade having an aperture is used to angularly diverge the beam, the beam being incident on the aperture in the shade.

23. The method of Claim 19, wherein a plano-convex lens having a focal length is used to collimate the beam, the plano-convex lens being disposed at a distance from the point along the beam path equal to the focal length.

24. The method of Claim 19, wherein a charge injection device (CID) is used to detect the pixel image.

25. The method of Claim 19, wherein a charge coupled device (CCD) is used to detect the pixel image.

26. The method of Claim 19, wherein a microcomputer is used to compute the dimensions.

27. The method of Claim 19, wherein a conveyor is used to position the workpiece.

28. The method of Claim 24, wherein the CCD device has a plurality of discrete, light sensitive sensors defining said pixels.

29. The method of Claim 25, wherein the CID device has a plurality of discrete, light sensitive sensors, defining said pixels.

30. The method of Claim 28, wherein the beam is incident on the CCD device for illuminating said discrete sensors.

31. The method of Claim 29, wherein the beam is incident on the CID device for illuminating said discrete sensors.

32. The method of Claim 29, wherein said silhouette is a collimated silhouette that is cast in a one-to-one dimensional relationship on said optical sensor array.

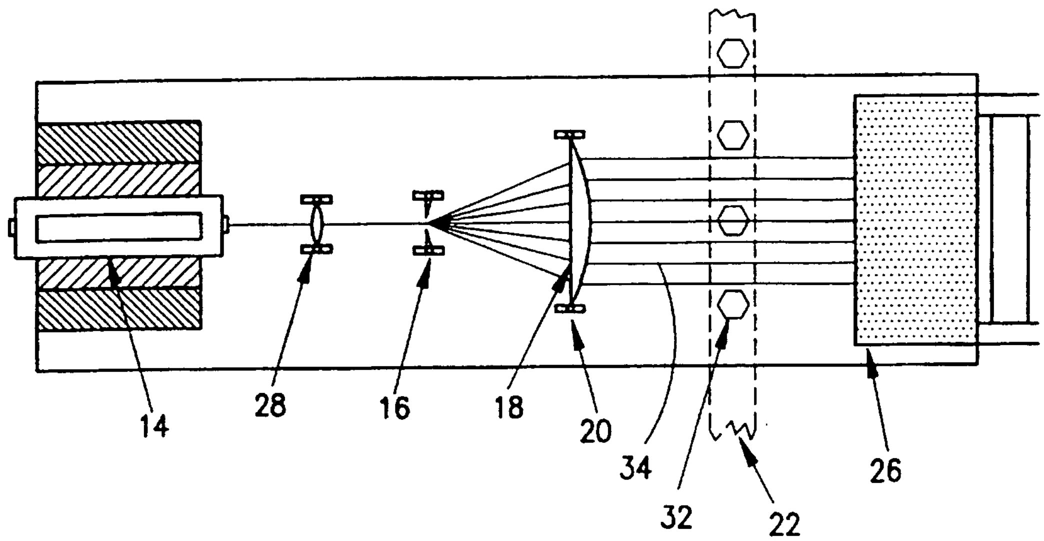

FIG. 1

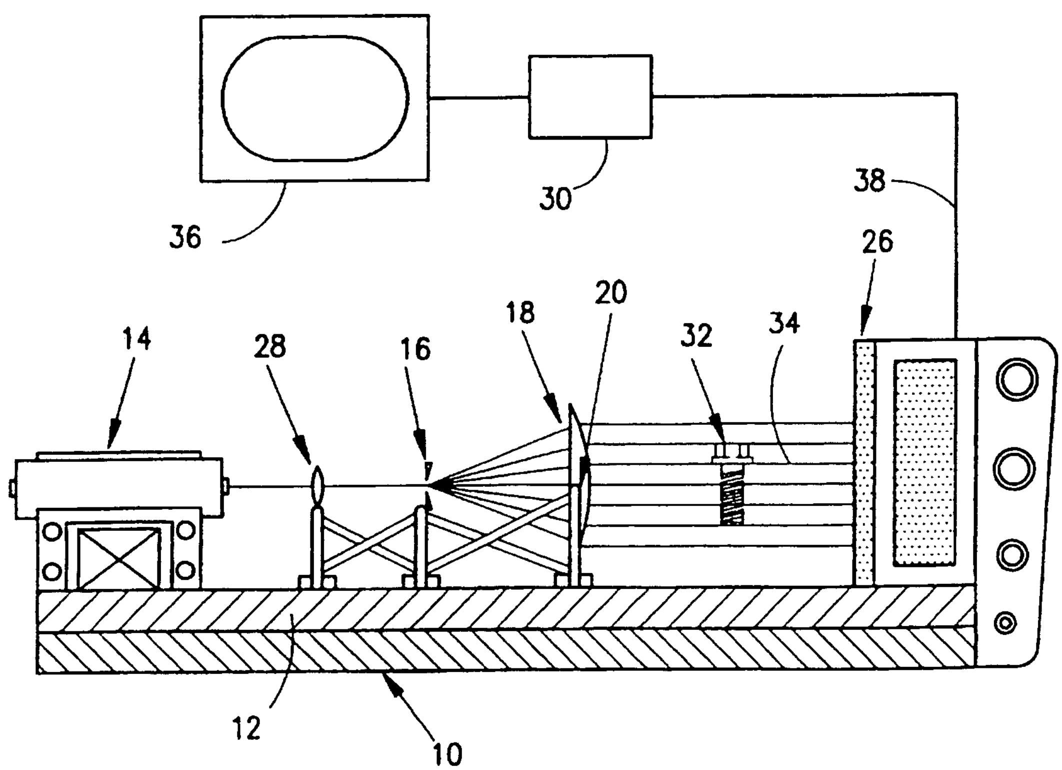

FIG. 2

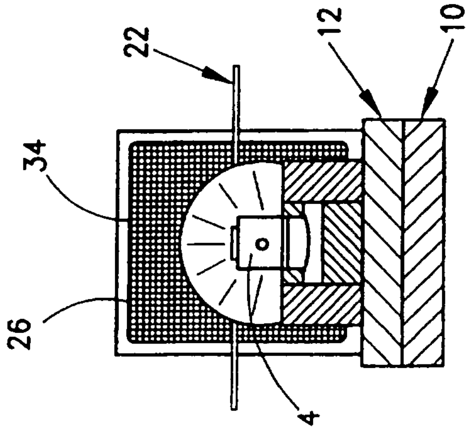

FIG. 3

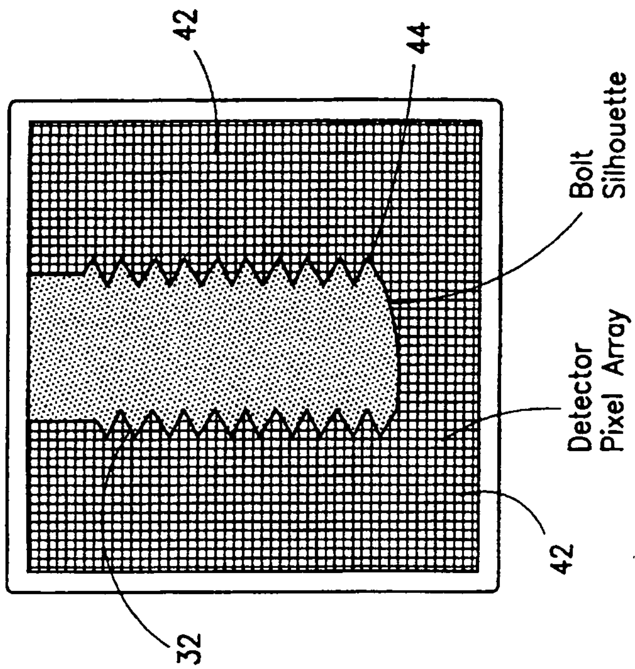

FIG. 4

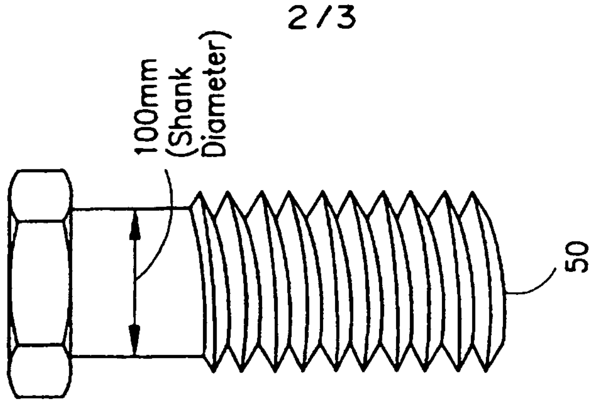

FIG. 5

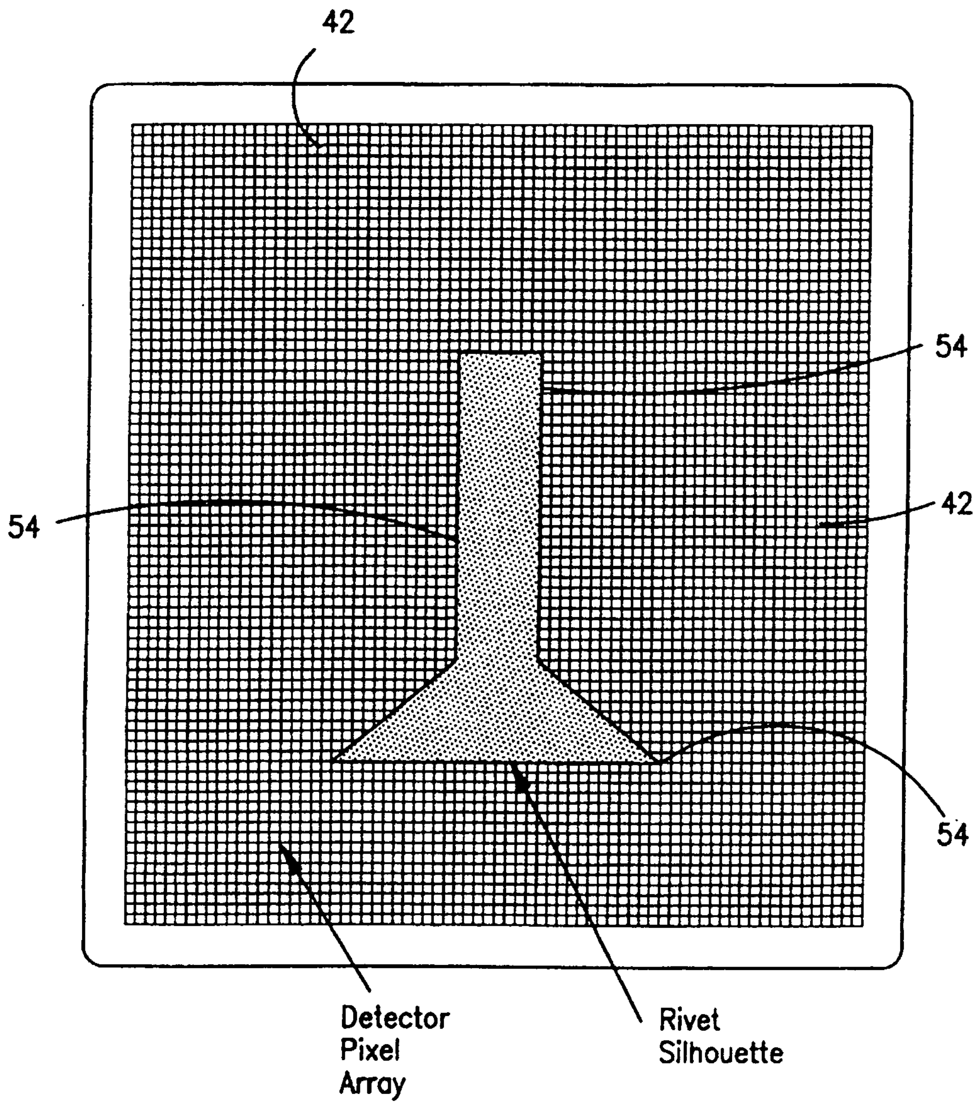

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/14950

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01B 11/ 02
US CL : 356/372
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 3,515,487 (HATCHER ET AL) 02 June 1970, see detector array 11 in figure 1.	1-32
Y	US, A, 3,549,896 (MASINO ET AL) 22 December 1970, see the collimated light beam and two-dimensional detector arrangement in figure 1.	1-32
Y	US, A, 3,549,890 (KELLER AT AL) 22 December 1970, see figure 1.	1-32
Y	US, A, 3,650,397 (BORNEMEYER) 21 March 1972, see figure 1.	1-32
Y	US, A, 5,383,021 (HANNA) 17 January 1995, see figures 3 and 6.	1-32

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 MAY 1996	23 MAY 1996

Name and mailing address of the ISA/US	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/14950

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,171,161 (JUNG) 16 October 1979, see figure 1	1-32
Y	US, A, 4,772,801 (FORNEROD ET AL) 20 September 1988, see figure 1.	1-32

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/14950

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

356/372, 378, 379, 383, 384, 385, 394, 240
250/559.12, 559.13, 559.15, 559.19, 559.21, 559.22, 559.24, 559.26